

# **A METHOD AND AN APPARATUS FOR ESTIMATING AN AMOUNT OF DRAWN AIR OF A CYLINDER OF AN INTERNAL-COMBUSTION ENGINE AND A METHOD AND AN APPARATUS FOR CONTROLLING THE AMOUNT**

## **BACKGROUND OF THE INVENTION:**

### **Field of the Invention:**

**[0001]** The present invention relates to a method and an apparatus for estimating an amount of drawn air of an internal-combustion engine. Further, the present invention relates to a method and an apparatus for controlling a value estimated by the above-mentioned method or apparatus for estimation, to a desired value. In particular, the present invention relates to a method and an apparatus for estimating an amount of drawn air, using an adaptive observer to identify a parameter and a method and an apparatus for controlling a value estimated by the above-mentioned method and apparatus for estimation, to a desired value.

### **Description of the Related Art:**

**[0002]** Fig. 1 shows a structure of an internal-combustion engine to which a method and an apparatus for estimating an amount of drawn air and a method and an apparatus for controlling a value estimated by the above-mentioned method and apparatus for estimation, to a desired value, according to the present invention, are applied. The internal-combustion engine in Fig. 1 is provided with a charger comprising a turbine 2 and a compressor 1 and a flexible valve timing mechanism 8. The turbine 2 and the compressor 1 may be mechanically or electrically connected. The flexible valve timing mechanism 8 may directly operate valves electrically or may electrically adjust valve operations carried out by mechanical cams. Further, in order to reduce emissions, the internal-combustion engine in Fig. 1 is provided with an airflow meter 3, an intake manifold pressure sensor (PB sensor) 6, a large area air-fuel ratio sensor (LAF sensor) 12, an oxygen sensor 15, a primary catalyst converter (highly heat-resistant and low thermal capacity CAT) 13 for early activation in starting stage and a main catalyst converter (high cell density CAT) 14 for high cleaning-up ratio of emissions during a period after the engine has been warmed up. In Fig. 1, a charging pressure sensor, an electronically controlled throttle, an exhaust gas recycling valve, an injector, a combustion

chamber and an ignition plug are represented respectively by reference numerals 4, 5, 7, 9, 10 and 11.

**[0003]** Fig. 2 shows an air-drawing section of the internal combustion engine. Air is fed through throttle 5 to the cylinder. Fig. 3 shows a relationship among an amount of air having passed through the throttle  $G_{th}$ , measured by the airflow meter 3, an amount of drawn air of the cylinder  $G_{cyl}$ , an amount of air filling the intake manifold  $G_b$  and an intake manifold pressure  $P_b$  measured by the intake manifold pressure sensor 6. Fig. 3 shows that an amount of air having passed through the throttle  $G_{th}$  will overshoot an amount of drawn air of the cylinder  $G_{cyl}$ , because of effect of filling the intake manifold. Accordingly, if an amount of air having passed through the throttle  $G_{th}$  is regarded as an amount of drawn air of the cylinder  $G_{cyl}$  to determine an amount of fuel to be injected, while the throttle is quickly moving, the air-fuel ratio will change as below. That is, the air-fuel ratio will become too large (fuel is too rich) when the opening is increased and will become too small (fuel is too lean) when the opening is decreased. As a result, the cleaning-up ratio of a catalyst will be reduced.

**[0004]** Conventionally, an amount of drawn air of the cylinder  $G_{cyl}$  has been estimated as mentioned below. A change in an amount of air filling the intake manifold  $\Delta G_b$  is estimated based on a change  $\Delta P_b$  in intake manifold pressure  $P_b$ , using the following equations.

$$P_b(k) V_b = G_b(b) R T_b \quad (1)$$

$$\Delta P_b(k) V_b = \Delta G_b(k) R T_b \quad (2)$$

$$\Delta G_b(k) = \Delta P_b(k) V_b / (R T_b) \quad (3)$$

**[0005]**  $V_b$ ,  $R$ ,  $T_b$  and  $k$  respectively represent a volume of the intake manifold, the gas constant, gas temperature in the intake manifold and control time synchronized with intake stroke (TDC) of the cylinder.  $T_b$  is assumed to be constant.

**[0006]** A change in an amount of air filling the intake manifold  $\Delta G_b(k)$  is used to adjust an amount of air having passed through the throttle  $G_{th}(k)$  using the following equation to obtain an estimated value of an amount of drawn air of the cylinder  $G_{cyl\_hat}(k)$ .

$$G_{cyl\_hat}(k) = G_{th}(k) \cdot \Delta G_b(k) \quad (4)$$

**[0007]** However, an effective volume of the intake manifold which contributes to the effect of filling the intake manifold, will vary depending on increase or decrease in the throttle opening and a changing rate of the throttle opening. Further, compensation for the overshoot of an amount of air having passed through the throttle  $G_{th}$ , might be excessive or insufficient, as shown in Fig. 4, depending on a change in a gas temperature  $T_b$  in the intake manifold. In order to deal with the problem, gain scheduling has been performed for a volume of the intake manifold, an estimated value of an amount of drawn air of the cylinder  $G_{cyl\_hat}(k)$  has been limited within limits or a change  $\Delta G_b$  in an amount of air filling the intake manifold has been subjected to filtering. As a result, the number of setting parameters for the above-mentioned methods has been increased. In spite of the efforts, the above-mentioned methods cannot deal with variation between engines or sensor properties and secular variation.

**[0008]** Publication of Japanese Unexamined Patent Application (KOKAI) No. 11-294231 discloses a method in which an estimated amount of drawn air is obtained using fuzzy-neural network. Refer to Figs. 9 and 10 of the application. However, even this method cannot resolve the above-mentioned problems.

**[0009]** Accordingly, there is a great need for a method and an apparatus for estimating an amount of drawn air, which can deal with variation between engines or sensor properties and secular variation, without increasing setting parameters. There is also a great need for a method and an apparatus for controlling a value estimated by the above-mentioned method and apparatus for estimation, to a desired value.

## **SUMMARY OF THE INVENTION:**

**[0010]** In the present invention an adaptive observer is used to estimate an amount of drawn air of a cylinder.

**[0011]** Thus, use of an adaptive observer allows accurate estimation of an amount of drawn air of a cylinder, independently of a moving rate and a moving direction of the throttle. As a result, control accuracy of air-fuel ratio is increased so that hazardous substances in exhaust gases can be reduced. Further, use of an adaptive observer remarkably reduces enormous

time and manpower for settings of algorithm for estimating an amount of drawn air, conventionally required.

**[0012]** A method for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to an embodiment of the present invention, comprises the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The method further comprises the step of determining a value of an identification parameter using an adaptive observer in such a way that a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the identification parameter, is made equal to a value of an amount of air having passed through the throttle. The method further comprises the step of multiplying the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, by the value of the identification parameter to obtain a final estimated value of an amount of drawn air of the cylinder.

**[0013]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to an embodiment of the present invention, comprises a module for obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure to deliver the estimated value as an output. The apparatus further comprises a module for determining an identification parameter using an adaptive observer, based on a value of intake manifold pressure and an amount of air having passed through a throttle. The apparatus further comprises a multiplying module for multiplying the estimated value, by a value of identification parameter to obtain a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter based on the estimated value of an amount of drawn air of the cylinder, in such a way that a product of the estimated value and a value of the identification parameter, is made equal to a value of an amount of air having passed through the throttle, to deliver the value of the identification parameter as an output.

**[0014]** A computer-readable medium, according to an embodiment of the present invention, has a program stored therein. The program is made to perform the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The program is made to further perform the step of determining a value of an identification parameter using an adaptive observer in such a way that a product of

the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the identification parameter, is made equal to a value of an amount of air having passed through the throttle. The program is made to further perform the step of multiplying the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, by the value of the identification parameter to obtain a final estimated value of an amount of drawn air of the cylinder.

**[0015]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to an embodiment of the present invention, comprises means for obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure to deliver the estimated value as an output. The apparatus further comprises means for determining an identification parameter using an adaptive observer. The apparatus further comprises means for multiplying the estimated value, by a value of identification parameter to obtain a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter based on the estimated value of an amount of drawn air of the cylinder, in such a way that a product of the estimated value and a value of the identification parameter, is made equal to a value of an amount of air having passed through the throttle, to deliver the value of the identification parameter as an output.

**[0016]** An amount of air having passed through the throttle, measured by the airflow meter, will show an overshoot when the throttle opening rapidly changes and will oscillate when the throttle opening remains invariant. As a result, accuracy of air-fuel ratio control is reduced. In the above-mentioned embodiment of the present invention, an estimated value of an amount of drawn air of the cylinder, based on intake manifold pressure, is multiplied by a value of an identification parameter obtained by an adaptive observer, to obtain a final estimated value of an amount of drawn air of the cylinder. The embodiment allows an accurate estimated value in a transient state as well as an estimated value not oscillating in a steady state. Accordingly, accuracy of air-fuel ratio control can be remarkably increased.

**[0017]** According to another embodiment of the present invention, when determining an identification parameter using an adaptive observer, an amount of lift of a exhaust gas recycling valve is further used for identification.

**[0018]** As recycling of waste gas is turned on or off, an amount of air having passed through the throttle, changes rapidly. The identification parameter calculated by the adaptive observer shows oscillation because of occurrences of spike errors. As a result, a final estimated value of drawn air of the cylinder, will sometimes be oscillating. In the present embodiment, an amount of lift of a exhaust gas recycling valve is used to cancel spike errors, to prevent a final estimated value of drawn air of the cylinder, from being oscillating. Accordingly, accuracy of air-fuel ratio control can be increased when recycling of waste gas is turned on or off.

**[0019]** A method for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to another embodiment of the present invention, comprises the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The method further comprises the step of obtaining an estimated value of an amount of recycled exhaust gas based on a value of intake manifold pressure, a value corresponding to pressure inside an exhaust manifold and a value of an amount of lift of an exhaust gas recycling valve. The method further comprises the step of determining values of first and second identification parameters using an adaptive observer, in a way shown below. A value obtained by subtracting a product of the estimated value of an amount of recycled exhaust gas and a value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the first identification parameter, is made equal to a value of an amount of air having passed through the throttle. The method further comprises the step of subtracting a product of the estimated value of an amount of recycled exhaust gas and the value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and the value of the first identification parameter, to obtain a final estimated value of an amount of drawn air of the cylinder.

**[0020]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to the present embodiment, comprises a module for obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, to deliver the estimated value of an amount of drawn air, as an output. The apparatus further comprises a module for obtaining an estimated value of an amount of

recycled exhaust gas based on a value of intake manifold pressure, a value corresponding to pressure inside an exhaust manifold and a value of an amount of lift of an exhaust gas recycling valve, to deliver the estimated value of an amount of recycled exhaust gas, as an output. The apparatus further comprises a module for determining first and second identification parameters using an adaptive observer to deliver values of the first and second identification parameters as outputs. The adaptive observer determines the identification parameters in a way shown below. A value obtained by subtracting a product of the estimated value of an amount of recycled exhaust gas and a value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the first identification parameter, is made equal to a value of an amount of air having passed through the throttle. The apparatus further comprises a module for subtracting a product of the estimated value of an amount of recycled exhaust gas and the value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and the value of the first identification parameter, to obtain and deliver as an output, a final estimated value of an amount of drawn air of the cylinder.

**[0021]** A computer-readable medium, according to the present embodiment, has a program stored therein. The program is made to perform the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The program is made to further perform the step of obtaining an estimated value of an amount of recycled exhaust gas based on a value of intake manifold pressure, a value corresponding to pressure inside an exhaust manifold and a value of an amount of lift of an exhaust gas recycling valve. The program is made to further perform the step of determining values of first and second identification parameters using an adaptive observer in a way shown below. A value obtained by subtracting a product of the estimated value of an amount of recycled exhaust gas and a value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the first identification parameter, is made equal to a value of an amount of air having passed through the throttle. The program is made to further perform the step of subtracting a product of the estimated value of an amount of recycled exhaust gas and the value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and the

value of the first identification parameter, to obtain a final estimated value of an amount of drawn air of the cylinder.

**[0022]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to the present embodiment, comprises means for obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, to deliver the estimated value of an amount of drawn air, as an output. The apparatus further comprises means for obtaining an estimated value of an amount of recycled exhaust gas based on a value of intake manifold pressure, a value corresponding to pressure inside an exhaust manifold and a value of an amount of lift of an exhaust gas recycling valve, to deliver the estimated value of an amount of recycled exhaust gas, as an output. The apparatus further comprises means for determining values of first and second identification parameters using an adaptive observer to deliver the first and second identification parameters as outputs. The adaptive observer determines the identification parameters in a way shown below. A value obtained by subtracting a product of the estimated value of an amount of recycled exhaust gas and a value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the first identification parameter, is made equal to a value of an amount of air having passed through the throttle. The apparatus further comprises means for subtracting a product of the estimated value of an amount of recycled exhaust gas and the value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and the value of the first identification parameter, to obtain and deliver as an output, a final estimated value of an amount of drawn air of the cylinder.

**[0023]** In the present embodiment, a final estimated value of an amount of drawn air of the cylinder, is obtained by subtracting a product of the estimated value of an amount of recycled exhaust gas and a value of the second identification parameter, from a product of the estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure and a value of the first identification parameter. Accordingly, a change in an actual amount of drawn air of the cylinder due to turning on and off of recycling of waste gas, can be reflected on the estimated value, without delay behind the turning on and off of recycling of waste gas. As



a result, accuracy of air-fuel ratio control can be increased when recycling of waste gas is turned on or off.

**[0024]** According to another embodiment of the present invention, when determining first and second identification parameters using an adaptive observer, a forgetting factor is used for the second identification parameter.

**[0025]** In the present embodiment, when an amount of air having passed through the throttle, remains invariant, the second parameter will become zero. Accordingly, an increase (a drift) in a sum of the absolute values of the first and second parameters, can be prevented when an amount of air having passed through the throttle, remains invariant. As a result, a remarkable decrease in accuracy of a final estimated value of an amount of drawn air of the cylinder, can be prevented.

**[0026]** A method for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to another embodiment of the present invention, comprises the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The method further comprises the step of obtaining a difference of values of intake manifold pressure, a second-order difference of values of intake manifold pressure, a difference of values of an amount of air having passed through a throttle and a difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The method further comprises the step of determining a value of an identification parameter using an adaptive observer. The method further comprises the step of subtracting a product of the difference of values of intake manifold pressure and the value of the identification parameter, from a value of an amount of air having passed through the throttle, to obtain a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter in such a way that a product of the second-order difference of values of intake manifold pressure and a value of the identification parameter, made equal to a value obtained by subtracting the difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, from the difference of values of an amount of air having passed through the throttle.

**[0027]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to the present embodiment, comprises a module for obtaining an

estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, to deliver the estimated value of an amount of drawn air, as an output. The apparatus further comprises at least one module for obtaining a difference of values of intake manifold pressure, a second-order difference of values of intake manifold pressure, a difference of values of an amount of air having passed through a throttle and a difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The apparatus further comprises a module for determining a value of an identification parameter using an adaptive observer and a module for multiplying the difference of values of intake manifold pressure by the value of the identification parameter. The apparatus further comprises a module for subtracting a product of the difference of values of intake manifold pressure and the value of the identification parameter, from a value of an amount of air having passed through the throttle, to obtain and deliver, as an output, a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter in such a way that a product of the second-order difference of values of intake manifold pressure and a value of the identification parameter, is made equal to a value obtained by subtracting the difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, from the difference of values of an amount of air having passed through the throttle.

**[0028]** A computer-readable medium, according to the present embodiment, has a program stored therein. The program is made to perform the step of obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The program is made to further perform the step of obtaining a difference of values of intake manifold pressure, a second-order difference of values of intake manifold pressure, a difference of values of an amount of air having passed through a throttle and a difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The program is made to further perform the step of determining a value of an identification parameter using an adaptive observer. The program is made to further perform the step of subtracting a product of the difference of values of intake manifold pressure and the value of the identification parameter, from a value of an amount of air having passed through the throttle, to obtain a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter in such a way that a product of the second-order difference of values of intake manifold pressure and a value of the

identification parameter, made equal to a value obtained by subtracting the difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, from the difference of values of an amount of air having passed through the throttle.

**[0029]** An apparatus for estimating an amount of drawn air of a cylinder of an internal combustion engine, according to the present embodiment, comprises means for obtaining an estimated value of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, to deliver the estimated value of an amount of drawn air, as an output. The apparatus further comprises at least means for obtaining a difference of values of intake manifold pressure, a second-order difference of values of intake manifold pressure, a difference of values of an amount of air having passed through a throttle and a difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure. The apparatus further comprises means for determining a value of an identification parameter using an adaptive observer and means for multiplying the difference of values of intake manifold pressure by the value of the identification parameter. The apparatus further comprises means for subtracting a product of the difference of values of intake manifold pressure and the value of the identification parameter, from a value of an amount of air having passed through the throttle, to obtain and deliver, as an output, a final estimated value of an amount of drawn air of the cylinder. The adaptive observer determines a value of the identification parameter in such a way that a product of the second-order difference of values of intake manifold pressure and a value of the identification parameter, is made equal to a value obtained by subtracting the difference of estimated values of an amount of drawn air of the cylinder, based on a value of intake manifold pressure, from the difference of values of an amount of air having passed through the throttle.

**[0030]** According to the present embodiment, a product of difference of values of intake manifold pressure and a value of the identification parameter, is subtracted from a value of an amount of air having passed through the throttle, to obtain a final estimated value of an amount of drawn air of the cylinder. A value of the identification parameter is determined by the adaptive observer, in such a way that a change in a final estimated value of an amount of drawn air of the cylinder, is made to coincide with a change in an estimated value of drawn air of the cylinder, based on intake manifold pressure. Accordingly, a first estimated value of drawn air of the cylinder shows behavior similar to behavior of an estimated value of drawn

air, based on intake manifold pressure, which is identical with behavior of an actual amount of drawn air of the cylinder in a transient state. As a result, accuracy of air-fuel ratio control can be increased in a transient state.

**[0031]** A method for controlling an amount of drawn air of a cylinder, according to still another embodiment of the present invention, further comprises the step of controlling the final estimated value of an amount of drawn air of the cylinder, obtained through a method for estimating an amount of drawn air of the cylinder, according to any one of embodiments of the present invention, to a desired value.

**[0032]** An apparatus for controlling an amount of drawn air of a cylinder, according to the present embodiment, comprises an apparatus for estimating an amount of drawn air of a cylinder according to any one of the embodiments of the present invention. The apparatus further comprises a controller receiving, as inputs, the final estimated value of the apparatus for estimating an amount of drawn air of a cylinder and a desired value of an amount of drawn air, to manipulate throttle opening in such a way that the final estimated value is controlled at the desired value.

**[0033]** According to the present embodiment, an estimated value of an amount of drawn air of the cylinder, obtained using the adaptive observer, according to any one of embodiments of the present invention, is controlled to a desired value. Accordingly, an amount of drawn air of the cylinder can be estimated with high accuracy, independently of a moving rate and a moving direction of the throttle. As a result, an amount of drawn air of the cylinder can be controlled with high accuracy, even when the throttle is required to move quickly. In other words, driving torque of the engine can be similarly controlled.

**[0034]** According to another embodiment, a response-specifying type control algorithm is used for the control.

**[0035]** Use of a response-specifying type control algorithm, allows control of an amount of drawn air of the cylinder, without generating an overshoot over a desired value. In other words, driving torque of the engine can be controlled, without generating an overshoot over a desired value of torque. As a result, drivability is enhanced as well as fuel efficiency is enhanced through reduction of wastes in HEV/GDI (a combination of a GDI engine and an electric motor) system.

## **BRIEF DESCRIPTION OF THE DRAWINGS:**

**[0036]** Fig. 1 shows a structure of an internal combustion engine to which a method and an apparatus for estimating an amount of drawn air and an apparatus for controlling a value estimated by the above-mentioned method and apparatus for estimation, to a desired value, according to the present invention, are applied.

**[0037]** Fig. 2 shows an air-drawing section of the internal combustion engine.

**[0038]** Fig. 3 shows a relationship between an amount of air having passed through the throttle  $G_{th}$  and an amount of drawn air of the cylinder  $G_{cyl}$ .

**[0039]** Fig. 4 shows behavior of an estimated value of an amount of drawn air of the cylinder when compensation for the overshoot of an amount of air having passed through the throttle  $G_{th}$ , is excessive or insufficient in a conventional system.

**[0040]** Fig. 5 shows a relationship among an amount of drawn air of the cylinder  $G_{cyl}$ , an amount of air having passed through the throttle  $G_{th}$  and an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on an amount of drawn air of the cylinder.

**[0041]** Fig. 6 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to an embodiment of the present invention.

**[0042]** Fig. 7 shows an estimated result of an amount of drawn air of the cylinder, according to an embodiment of the present invention.

**[0043]** Fig. 8 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to another embodiment of the present invention.

**[0044]** Fig. 9 shows an estimated result of an amount of drawn air of the cylinder, according to another embodiment of the present invention.

**[0045]** Fig. 10 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to another embodiment of the present invention.

**[0046]** Fig. 11 shows an estimated result of an amount of drawn air of the cylinder, according to another embodiment of the present invention.

[0047] Fig. 12 shows behavior of error  $G_e$  converging to zero.

[0048] Fig. 13 shows a result of an amount of drawn air of the cylinder  $G_{cyl}$ , controlled by the response-specifying type controller.

[0049] Fig. 14 shows a configuration of a fuel-injection control system comprising an apparatus for estimating an amount of drawn air and a response-specifying type controller for controlling an amount of drawn air, according to an embodiment of the present invention.

[0050] Fig. 15 shows a procedure of a method for estimating an amount of drawn air, according to an embodiment of the present invention.

[0051] Fig. 16 shows an example of an electronic control unit used in embodiments of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0052] An embodiment of the present invention will be described below.

[0053] At first, a gas at intake manifold pressure  $P_b$  is assumed to be charged into the cylinder without considering a filling efficiency, and an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, is calculated using the following equation.

$$P_b(k) V_{cyl} = G_{air\_Pb}(k) R T_{cyl} \quad (5)$$

[0054]  $V_{cyl}$ ,  $R$ ,  $T_{cyl}$  and  $k$  respectively represent a volume of the cylinder (a effective compressed volume of the cylinder in the case of flexible valve timing mechanism), the gas constant, gas temperature in the cylinder and control time synchronized with TDC. Gas temperature in the cylinder  $T_{cyl}$  is assumed to be equal to gas temperature in the intake manifold  $T_b$ . The above equation (5) is transformed into the following equation (6).

$$G_{air\_Pb}(k) = (P_b(k) V_{cyl}) / (R T_{cyl}) \quad (6)$$

[0055] In this case, a relationship among an amount of drawn air of the cylinder Gcyl, an amount of air having passed through the throttle Gth and an estimated value Gair\_Pb of an amount of drawn air of the cylinder, obtained using intake manifold pressure, is shown in Fig. 5. Since a filling efficiency is neglected, there is an offset between an estimated value Gair\_Pb of an amount of drawn air of the cylinder and an amount of drawn air of the cylinder Gcyl. However, behavior of the estimated value corresponds to that of an amount of drawn air of the cylinder Gcyl. In the present embodiment, attention has been focused on this characteristic of an estimated value Gair\_Pb of an amount of drawn air of the cylinder.

[0056] In other words, an estimated value Gair\_Pb of an amount of drawn air of the cylinder has information on behavior of an amount of drawn air of the cylinder Gcyl, while an amount of air having passed through the throttle Gth has information on a filling efficiency of the cylinder. Accordingly, a method has been invented, in which an amount of air having passed through the throttle Gth is used to compensate for an offset of an estimated value Gair\_Pb of an amount of drawn air of the cylinder.

[0057] Since a filling efficiency of the cylinder is not constant, an offset between an estimated value Gair\_Pb of an amount of drawn air of the cylinder and an amount of drawn air of the cylinder Gcyl, is not constant in a strict sense. Accordingly, adjustment of an estimated value Gair\_Pb of an amount of drawn air of the cylinder, through an amount of drawn air of the cylinder Gcyl, must be adaptive.

[0058] For this reason, in the present invention an adaptive observer is used to make adaptive adjustment. Particularly, in the present embodiment, a recursive identification algorithm is used as an adaptive observer, to adjust an estimated value Gair\_Pb of an amount of drawn air of the cylinder, using identification parameter A' to obtain a final estimated value Gcyl\_hat of an amount of drawn air of the cylinder, as shown below.

$$Gcyl\_hat(k) = A'(k) Gair\_Pb(k) \quad (7)$$

$$A'(k) = A'(k-1) + KP'(k) (ide'(k) - Klact \Delta LACT) \quad (8)$$

$$KP(k) = \frac{P'(k-1)Z'(k)}{1 + Z'(k)P'(k-1)Z'(k)} \quad (9)$$

$$ide'(k) = Gth(k) \cdot A'(k-1) Gair\_Pb(k) \quad (10)$$

$$P'(k+1) = \frac{1}{\lambda_1} \left( 1 - \frac{\lambda_2 P'(k) Z'(k) Z'(k)}{\lambda_1 + \lambda_2 Z'(k) P'(k) Z'(k)} \right) P'(k) \quad (11)$$

$$Z'(k) = Gair\_Pb(k) \quad (12)$$

$$\Delta LACT = LACT(k) \cdot LACT(k-1) \quad (13)$$

**[0059]**  $\lambda_1$  and  $\lambda_2$  represent weighting parameters.  $LACT$  and  $Klact$  respectively represent an amount of lift of the exhaust gas recycling (EGR) valve and a damping factor. When  $\lambda_1 = 1$  and  $\lambda_2 = 1$ , the method is least square. When  $\lambda_1 < 1$  and  $\lambda_2 = 1$ , the method is weighted least square. When  $\lambda_1 = 1$  and  $\lambda_2 = 0$ , the method is of fixed gain. When  $\lambda_1 = 1$  and  $\lambda_2 < 1$ , the method is of gradually decreasing gain. Identification parameter  $A'$  is determined in such a way that an error in Equation (10) is minimized.

**[0060]** Term  $\Delta LACT$  of in Equation (8) is a term for damping to control oscillation of a final estimated value  $Gcyl\_hat$  of an amount of drawn air of the cylinder, in the case of a sudden change in an amount of lift of the EGR valve. In the case of a sudden change in an amount of lift of the EGR valve, a filling efficiency of the cylinder will suddenly change to cause a spike error. This will have identification parameter  $A'$  oscillate. The above-mentioned term for damping is intended to prevent oscillation of the identification parameter.

**[0061]** Fig. 6 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to the present embodiment. The apparatus for estimating an amount of drawn air of the cylinder, comprises a module 61, a module 62 and a multiplying module 63. The module 61 receives a value of intake manifold pressure  $Pb$  as input, obtains an estimated value  $Gair\_Pb$  of an amount of drawn air of the cylinder and delivers the



estimated value as output [Equation (6)]. The module 62 receives an amount of air having passed through the throttle Gth, the estimated value Gair\_Pb of an amount of drawn air of the cylinder and an amount of lift of the exhaust gas recycling (EGR) valve LACT, as inputs, determines an identification parameter A', using recursive least square method and delivers the parameter as output [Equations (8) to (13)]. Identification parameter A' is determined in such a way that an error in Equation (10) is minimized. The multiplying module 63 multiplies the estimated value Gair\_Pb of an amount of drawn air of the cylinder by the identification parameter A' to obtain a final estimated value Gcyl\_hat of an amount of drawn air of the cylinder [Equation (7)].

**[0062]** Fig. 7 shows an estimated result of an amount of drawn air of the cylinder, according to the present embodiment. Even when an amount of air having passed through the throttle Gth or an amount of lift of the EGR valve LACT, changes, a final estimated value Gcyl\_hat of an amount of drawn air of the cylinder, follows a value of an amount of drawn air of the cylinder Gcyl. The identification parameter A' changes depending on a change in an amount of air having passed through the throttle Gth and a change in an amount of lift of the EGR valve LACT.

**[0063]** Another embodiment of the present invention will be described below.

**[0064]** In the present embodiment, an amount of exhaust gas Gegr recycled through EGR passage, is estimated using the following equation.

$$Gegr(k) = Kgegr LACT(k-d) \sqrt{Pa - Pb} \quad (14)$$

**[0065]** Kgegr, LACT and Pa respectively represent a calculation factor for a recycled amount of exhaust gas, an amount of lift of the valve and atmospheric pressure. Atmospheric pressure is substantially equal to pressure (back pressure) of exhaust gas.

**[0066]** A final estimated value Gcyl\_hat of an amount of drawn air of the cylinder, is calculated using the following equation.

$$Gcyl\_hat(k) = A''(k)Gair\_Pb(k) - B''(k) Gegr(k) \quad (15)$$

**[0067]**  $A''$  and  $B''$  represent identification parameters. An estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder will not reflect an effect of a recycled amount of exhaust gas (EGR). However, Equation (15) will eliminate an excessive portion of an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, caused by an increase in pressure  $P_b$  due to the recycled amount of exhaust gas (EGR).

**[0068]** A procedure by which Equation (15) is calculated using recursive least square method, is shown with the following equations.

$$G_{cyl\_hat}(k) = A''(k)G_{air\_Pb}(k) - B''(k)G_{egr}(k) \quad (16)$$

$$\theta''(k) = \delta \theta''(k-1) + KP''(k)ide''(k) \quad (17)$$

$$KP''(k) = \frac{P''(k-1)Z''(k)}{1 + Z''(k)^T P''(k-1)Z''(k)} \quad (18)$$

$$ide''(k) = G_{th}(k) - \theta''(k-1)^T Z''(k) \quad (19)$$

$$Z''(k)^T = [G_{air\_Pb}(k) \ G_{egr}(k)] \quad (20)$$

$$\theta''(k)^T = [A''(k), -B''(k)] \quad (21)$$

$$\delta = \begin{bmatrix} 1 & 0 \\ 0 & \delta \end{bmatrix} : \text{Forgetting Vector } (0 < \delta < 1) \quad (22)$$

**[0069]**  $\theta''$  ( $A''$ ,  $B''$ ) represents identification parameters, while  $P''$  represents an identification gain.

**[0070]** Since in Equations (17) to (22), there exist more than one identification parameters, a drift might occur when an amount of air having passed through the throttle  $G_{th}$  remains substantially constant. Accordingly, a fixed gain algorithm using  $\sigma$ -correction method, is employed as algorithm for identification.

**[0071]** Fig. 8 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to the present embodiment. The apparatus for estimating an amount of drawn air of the cylinder, comprises a module 81, a module 82, a module 83 and a module 84. The module 81 receives a value of intake manifold pressure  $P_b$  as input, obtains an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder and delivers the estimated value as output [Equation (6)]. The module 82 receives a value of intake manifold pressure  $P_b$ , a value of atmospheric pressure  $P_a$  and a value of an amount of lift of the exhaust gas recycling valve LACT, as inputs, obtains an estimated value  $G_{erg}$  of an amount of recycled exhaust gas based on intake manifold pressure and delivers the estimated value as output [Equation (14)]. The module 83 receives an amount of air having passed through the throttle  $G_{th}$ , the estimated value  $G_{erg}$  of an amount of recycled exhaust gas, based on intake manifold pressure and the estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, as inputs, obtains the first identification parameter  $A^*$  and the second identification parameter  $B^*$ , using recursive least square mean method and delivers the identification parameters as outputs [Equations (17) to (22)]. The first and second identification parameters  $A^*$  and  $B^*$  are determined in such a way that an error in Equation (19) is minimized. The module 84 obtains a first product of the estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure and the first identification parameter  $A^*$ . The module 84 obtains a second product of the estimated value  $G_{erg}$  of an amount of recycled exhaust gas, based on intake manifold pressure and the second identification parameter  $B^*$ . Then, the module 84 subtracts the second product from the first product to obtain a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder [Equation (16)].

**[0072]** Fig. 9 shows an estimated result of an amount of drawn air of the cylinder, according to the present embodiment. Even when an amount of air having passed through the throttle  $G_{th}$  or an amount of lift LACT of the EGR valve, changes, a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, follows a value of an amount of drawn air of

the cylinder  $G_{cyl}$ . The first identification parameter  $A^*$  changes depending on a change in an amount of air having passed through the throttle  $G_{th}$  and a change in an amount of lift  $LACT$  of the EGR valve. The second identification parameter  $B^*$  changes depending on a change in an amount of lift  $LACT$  of the EGR valve and returns back to zero in a steady state. Such behaviors of the identification parameters allow estimation with high-accuracy even at a sudden change in an amount of lift of the EGR valve.

**[0073]** Still another embodiment of the present invention will be described below.

**[0074]** An estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, has precise information on a change in an amount of drawn air of the cylinder. Accordingly, a change  $\Delta \square \square$  in an amount of gas filling the intake manifold is adaptively calculated in such a way that a change in a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, is made to coincide with a change in an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure.

**[0075]** Conventionally, an estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, is calculated using the following equation.

$$G_{cyl\_hat}(k) = G_{th}(k) - \Delta G_b(k) \quad (4)$$

$$\Delta G_b(k) = \Delta P_b(k) V_b / (R T_b) \quad (3)$$

**[0076]** The conventional method mentioned above has the problem that a change  $\Delta G_b$  in an amount of gas filling the intake manifold, cannot be properly set for variation between engines or sensor properties and secular variation.

**[0077]** Therefore, an estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, is newly defined by the following equation.

$$G_{cyl\_hat}(k) = G_{th}(k) - A \Delta P_b(k) \quad (23)$$

**[0078]** It should be noted that identification parameter A is used to adaptively calculate a change  $\Delta G_b$  in an amount of gas filling the intake manifold.

**[0079]** A difference of Equation (23) is obtained as below.

$$\Delta G_{cyl\_hat}(k) = \Delta G_{th}(k) \cdot A \Delta \Delta P_b(k) \quad (24)$$

$$\Delta G_{cyl\_hat}(k) = G_{cyl\_hat}(k) - G_{cyl\_hat}(k-1) \quad (25)$$

$$\Delta G_{th}(k) = G_{th}(k) - G_{th}(k-1) \quad (26)$$

$$\Delta \Delta P_b(k) = \Delta P_b(k) - \Delta P_b(k-1) \quad (27)$$

**[0080]** A difference of an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, is defined by the following equation.

$$\Delta G_{air\_Pb}(k) = G_{air\_Pb}(k) - G_{air\_Pb}(k-1) \quad (28)$$

**[0081]** The condition that a change in a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, coincides with a change in an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, is represented by the following equation.

$$\Delta G_{air\_Pb}(k) = \Delta G_{cyl\_hat}(k) \quad (29)$$

**[0082]** Substituting Equation (24) to the right side of Equation (29) leads to the following equation.

$$\Delta G_{th}(k) \cdot \Delta G_{air\_Pb}(k) = A \Delta \Delta P_b(k) \quad (30)$$

**[0083]** Thus, identification parameter A should be defined in such a way that Equation (30) is satisfied, to calculate a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder. A method by which the final estimated value is calculated, is shown specifically by the following equations.

$$G_{cyl\_hat}(k) = G_{th}(k) \cdot A \Delta P_b(k) \quad (31)$$

$$A(k) = A(k-1) + KP(k) ide(k) \quad (32)$$

$$KP(k) = \frac{P'(k-1)Z(k)}{1 + Z(k)P(k-1)Z(k)} \quad (33)$$

$$\begin{aligned} ide(k) &= \Delta G_{th}(k) - \Delta G_{air\_Pb}(k) - A \Delta P_b(k) \\ &= \Delta G_{th}(k) - \Delta G_{air\_Pb}(k) - A Z(k) \end{aligned} \quad (34)$$

$$P(k+1) = \frac{1}{\lambda_1} \left( 1 - \frac{\lambda_2 P(k) Z(k) Z(k)}{\lambda_1 + \lambda_2 Z(k) P(k) Z(k)} \right) P(k) \quad (35)$$

$$Z(k) = \Delta \Delta P_b(k) \quad (36)$$

$\lambda_1$  and  $\lambda_2$  represent weighting parameters.

**[0084]** Fig. 10 shows a block diagram of an apparatus for estimating an amount of drawn air of the cylinder, according to the present embodiment. The apparatus for estimating an amount of drawn air of the cylinder, comprises modules 101 to 108. The module 101 receives a value of intake manifold pressure  $P_b$  as input, obtains an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure and delivers the estimated value as output [Equation (6)]. The modules 102 to 105 are devices for obtaining differences. The module 106 receives a difference  $\Delta G_{th}$  of an amount of air having passed through the throttle, a second order difference  $\Delta \Delta P_b$  of intake manifold pressure and a

difference  $\Delta G_{air\_Pb}$  of an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder, based on intake manifold pressure, as inputs. Then, the module 106 determines identification parameter A in such a way that a change in a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, is made to coincide with a change in an estimated value  $G_{air\_Pb}$  of an amount of drawn air of the cylinder [Equations 32 to 36]. More specifically, the identification parameter A is determined in such a way that an error in Equation (34) is minimized. The module 107 multiplies the estimated value  $G_{air\_Pb}$  by identification parameter A. The module 108 subtracts the result of the multiplication from an amount of air having passed through the throttle  $G_{th}$ , to obtain a final estimated value  $G_{cyl\_hat}$ [Equation (31)].

**[0085]** Fig. 11 shows an estimated result of an amount of drawn air of the cylinder, according to the present embodiment. Even when an amount of air having passed through the throttle  $G_{th}$  changes, a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, follows a value of an amount of drawn air of the cylinder  $G_{cyl}$ . The identification parameter A changes depending on a change in an amount of air having passed through the throttle  $G_{th}$ .

**[0086]** In the embodiments shown in Figs. 6 and 8, behavior of a final estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, in a transient state, is followed by recursive least square method having delay in response. Accordingly, when a convergence speed for an offset in a steady state between an amount of drawn air of the cylinder  $G_{cyl}$  and a final estimated value  $G_{cyl\_hat}$ , is increased, behavior of a final estimated value  $G_{cyl\_hat}$ , approaches that of a value of an amount of air having passed through the throttle  $G_{th}$ . On the other hand, in the embodiments shown in Figs. 6 and 8, air-fuel ratio control in a steady state is considerably stable, because oscillations of an amount of air having passed through the throttle  $G_{th}$ , in a steady state is subjected to filtering.

**[0087]** In the embodiment shown in Fig. 10, a convergence speed for an offset in a steady state, can be increased, while oscillations of an amount of air having passed through the throttle  $G_{th}$ , in a steady state cannot be subjected to filtering.

**[0088]** A method by which an estimated value  $G_{cyl\_hat}$  of an amount of drawn air of the cylinder, is controlled to a desired value  $G_{cyl\_cmd}$ , will be described below. The value

Gcyl\_hat has been estimated by one of the apparatuses for estimating an amount of drawn air of the cylinder, according to the present invention, mentioned above.

**[0089]** A relationship between opening TH and a desired value TH\_com of an electronically controlled throttle, can be approximated by the following equation.

$$TH(k) = Ath TH(k-1) + Bth TH\_cmd(k) \quad (37)$$

Ath and Bth are constants a sum of which is 1.

**[0090]** Further, an amount of air having passed through the throttle can be approximated by the following equation.

$$Gth'(k) = Sth(Pa,Pb,TH) TH(k) \quad (38)$$

**[0091]** Sth is a factor determined depending on atmospheric pressure Pa (substantially equal to a pressure at a point upstream the throttle), intake manifold pressure Pb and throttle opening TH.

**[0092]** The following equation is obtained from Equations (37) and (38).

$$\begin{aligned} Gth'(k) &= Sth(Pa,Pb,TH) TH(k) \\ &= Sth(Pa,Pb,TH) Ath TH(k-1) + Sth(Pa,Pb,TH) Bth TH\_cmd(k) \\ &= Ath Gth'(k-1) + Bth' TH\_cmd(k) \end{aligned} \quad (39)$$

$$Bth' = Sth (Pa, Pb, TH) Bth$$

**[0093]** Further, since an amount of air having passed through the throttle Gth is substantially equal to an approximated value Gth', a relationship between Gth' and Gcyl\_hat can be approximated by the following equation.



$$\begin{aligned}
G_{cyl\_hat}(k) &= G_{th}'(k) \cdot \Delta G_b(k) \\
&= G_{th}'(k) \cdot A (P_b(k) - P_b(k-1))
\end{aligned} \tag{40}$$

**[0094]** The following equations can be obtained by substituting Equation (39) into Equation (40).

$$\begin{aligned}
G_{cyl\_hat}(k) &= G_{th}'(k) \cdot A P_b(k) + A P_b(k-1) \\
&= A_{th} G_{th}'(k-1) + B_{th}' TH\_cmd(k) \cdot A P_b(k) + A P_b(k-1)
\end{aligned} \tag{41}$$

$$G_{cyl\_hat}(k) = A_{th} G_{th}'(k-1) \cdot A P_b(k) + A P_b(k-1) + B_{th}' TH\_cmd(k) \tag{42}$$

**[0095]** In the following equation,  $G_{th}'$  in Equation (42) is replaced with a measured value  $G_{th}$  from the air-flow meter.

$$G_{cyl\_hat}(k) = A_{th} G_{th}(k-1) \cdot A P_b(k) + A P_b(k-1) + B_{th}' TH\_cmd(k) \tag{43}$$

**[0096]** Equation (43) described above, is assumed to be a model which represents a relationship between a desired value  $TH\_com$  of throttle opening and an estimated value  $G_{cyl\_hat}$  of an amount of drawn air.

**[0097]** An error between an estimated value  $G_{cyl\_hat}$  of an amount of drawn air and a desired value  $G_{cyl\_cmd}$  of an amount of drawn air, is defined by the following equation.

$$Ge(k) = G_{cyl\_hat}(k) - G_{cyl\_cmd}(k) \quad (44)$$

**[0098]** Further, convergence behavior of  $Ge$  is defined by the following switch function  $\sigma$ .

$$\sigma(k) = Ge(k) \cdot S \cdot Ge(k-1) \quad (45)$$

where  $-1 < S < 1$ . The switch function is represented as below.

$$Ge(k) = S \cdot Ge(k-1) \quad (46)$$

**[0099]** The switch function means that error  $Ge$  will converge to zero with behavior of a first-order delay system without an input, as shown in Fig. 12.

**[0100]** A response-specifying type controller which will realize convergence behavior specified by the switch function  $\sigma$ , is represented as below.

$$\begin{aligned} TH\_cmd'(k) = & -K_{eq0} G_{cyl\_hat}(k) - K_{eq1} G_{th}(k-1) - K_{eq2} Pb(k) \\ & - K_{eq3} Pb(k-1) - K_{rch} \sigma(k) - K_{adp} \sum_{i=0}^k \sigma(i) \end{aligned} \quad (47)$$

**[0101]** Feedback gains  $K_{eq0}$ ,  $K_{eq1}$ ,  $K_{eq2}$ ,  $K_{eq3}$ ,  $K_{rch}$  and  $k_{adp}$  are determined to minimize the estimation function described below.

$$J = \sum_{j=0}^k \Delta X(j)^T Q \Delta X(j) + \Delta TH\_cmd'(j)^T R \Delta TH\_cmd'(j) \quad (48)$$

$$\Delta X(k) = [\Delta Gcyl\_hat(k) \Delta Gth(k) \Delta Pb(k) \Delta Pb(k-1) \Delta \sigma(k) \sigma(k)]^T \quad (49)$$

$$Q = \begin{bmatrix} q1 & 0 & 0 & 0 & 0 & 0 \\ 0 & q2 & 0 & 0 & 0 & 0 \\ 0 & 0 & q3 & 0 & 0 & 0 \\ 0 & 0 & 0 & q4 & 0 & 0 \\ 0 & 0 & 0 & 0 & q5 & 0 \\ 0 & 0 & 0 & 0 & 0 & q6 \end{bmatrix} \quad (50)$$

$$R = r0 \quad (51)$$

**[0102]** Q represents a set of weighting parameters, while q1, q2, q3, q4, q5, q6 and r0 are positive constants. If weighting factors are set as shown below, a convergence to zero of  $\Delta \sigma$  and  $\sigma$  can be made faster than a convergence to zero of each of state variables  $\Delta Gcyl\_hat(k)$ ,  $\Delta Gth(k)$ ,  $\Delta Pb(k)$  and  $\Delta Pb(k-1)$ . In other words, responses of specified errors can be made faster. Further, robust stability for modeling error and disturbances in the control system, can be improved

$$q1, q2, q3, q4 \leq q5, q6 \quad (52)$$

**[0103]** Further, feedforward opening  $TH\_ff$  is added to  $TH\_cmd$  in Equation (47) to obtain a desired value of throttle opening, that is, a controlled variable  $TH\_cmd$  of throttle opening in the response-specifying type controller. Feedforward opening  $TH\_ff$  is obtained based on accelerator pedal opening AP, vehicle velocity VP, transmission shift position NGEAR, charging pressure Pc, presence or absence of electric load and state of being turned on or off of the hydraulic pump for power steering.

$$\begin{aligned}
TH\_cmd(k) &= TH\_ff(k) + TH\_cmd'(k) \\
&= TH\_ff(k) \cdot Keq0 \cdot Gcyl\_hat(k) \cdot Keq1 \cdot Gth(k-1) \cdot Keq2 \cdot Pb(k) \\
&\quad - Keq3 \cdot Pb(k-1) \cdot Krch \cdot \sigma(k) \cdot Kadp \cdot \sum_{i=0}^k \sigma(i)
\end{aligned} \tag{53}$$

**[0104]** Fig. 13 shows a result of an amount of drawn air of the cylinder  $Gcyl$ , controlled by the response-specifying type controller.

**[0105]** Fig. 14 shows a configuration of a fuel-injection control system comprising the apparatus for estimating an amount of drawn air and the response-specifying type controller for controlling an amount of drawn air, according to the embodiment of the present invention.

**[0106]** The response-specifying type controller 1002 receives, as inputs, an estimated value of an amount of drawn air of the cylinder, from the apparatus 1001 for estimating an amount of drawn air of the cylinder and a desired value of an amount of drawn air of the cylinder, from a section 1003 for calculating a desired value of an amount of drawn air of the cylinder. The response-specifying type controller 1002 manipulates throttle opening to have an estimated value controlled at a desired value. In Fig. 14, a fuel conversion module and a fuel adhesion correction module are represented with reference numerals 1004 and 1005, while fuel correction factor calculating modules are represented with reference numerals 1006 and 1007. These modules determine an amount of fuel to be injected.

**[0107]** In Fig. 14 throttle opening is manipulated to control an amount of drawn air of the cylinder. Alternatively, an amount of drawn air of the cylinder can be controlled by flexible valve timing mechanism. Further, in a system with a motor-driven compressor, an amount of drawn air of the cylinder can be controlled by adjusting voltage to be applied to the motor-driven compressor. In a system provided with a turbine with a waste gate, an amount of drawn air of the cylinder can be controlled by controlling the waste gate to control a charging pressure.

**[0108]** Fig. 15 shows a procedure of a method for estimating an amount of drawn air, according to an embodiment of the present invention. Calculations of the procedure are

carried out for each intake stroke (TDC). In step S10, values Pb\_buf of intake manifold pressure sampled at certain crank angles (CRK) determined by dividing TDC into 6 equal parts, are subjected to 6-tap moving averaging to remove pulsing components of Pb\_buf. For example, a crank angle for an intake stroke (TDC) is 180 degrees, and a crank angle (CRK) signal is delivered for every 30 degrees of crank rotation angle. In step S20, it is determined whether or not the airflow meter is active. If active, the process goes to step 30, in which values Gth\_buf of an amount of air having passed through the throttle, are subjected to 6-tap moving averaging to remove pulsing components of Gth\_buf. In step S40, an estimated value Gcyl\_hat of an amount of drawn air of the cylinder, is calculated. In step S50, a desired value TH\_cmd of throttle opening is calculated. If the airflow meter is determined to be not active in step S20, the process goes to step S60, in which an estimated value Gcyl\_hat of an amount of drawn air of the cylinder, is calculated based on the number of revolutions of the engine and intake manifold pressure. In step S70, a desired value TH\_cmd of throttle opening is made equal to accelerator pedal opening. At this time, when the accelerator pedal is fully closed, a certain opening is given to allow the engine to maintain an idling speed. In other words, when the accelerator pedal is fully closed, TH\_cmd is determined by idling speed control not shown.

**[0109]** An example of an electronic control unit used in embodiments of the present invention, will be described with reference to Fig. 16. The electronic control unit includes a CPU 1601, a ROM 1611, a flash memory 1612, a RAM 1613, an I/O unit 1614 and a communication controller 1615 for a network on the vehicle. The above devices are connected with one another via a bus 1620.

**[0110]** Algorithm for estimating and controlling an amount of drawn air of a cylinder, according to the present invention, may be stored as a program in the ROM 1611 or the flash memory 1612. Some part of the algorithm, for example fuzzy rules, may be stored in the flash memory 1612, while the other part may be stored in the ROM 1611. Alternatively, the algorithm may be stored in another type of memory not shown in the drawing.